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ICEBERG SPLITTING AND ITS IMPLICATIONS FOR DETERIORATION MODELLING

Deborah Diemand James H. Lever

Centre for Cold Ocean Resources Engineering
Memorial University of Newfoundland
St. John's, Newfoundland, A1B 3X5, Canada

ABSTRACT

Many iceberg deterioration models have been developed recently to supply a need by offshore operators to predict the numbers and sizes of icebergs likely to impinge on a specific area of interest such as a drilling site or wellhead. The more sophisticated models incorporate many environmental parameters such as wind direction and speed, currents, waves, air and water temperatures, etc., as well as factors intended to account for mass loss due to melting and calving. These factors are based on ablation rates as determined by laboratory studies, field observations and theoretical considerations and are reliable to a degree. They are predicated on the belief that mass loss in icebergs is a result of two mechanisms: melting and calving of small fragments. Observations on Makkovik Bank during the summer of 1985 make it clear that this is only partly true and that major calving events such as ram loss and iceberg splitting are quite common and should be accounted for in any deterioration model, as failure to do so will result in underestimation of of numbers and overesimation of sizes. Various mass loss mechanisms were documented and are discussed in terms of their implications for iceberg deterioration and model design.

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1. INTRODUCTION

The population of icebergs on the Grand Banks of Newfoundland, or any other area south of Baffin Bay for that matter, is largely dependent on the deterioration rate experienced on the journey south from Baffin Bay. A number of models have been devised in an effort to predict iceberg drift and population density. Statistical correlations have been made between total iceberg counts and various environmental parameters in an effort to discover the best indicators of iceberg season severity. Complex operational deterioration models may also be applied to seasonal forecasts, but with high demands on input information. Either approach may be ineffectual if they are predicated on the notion that an individual iceberg will remain intact for the duration of its life, gradually diminishing through various ablation mechanisms. The observation this summer on DIGS '85 that icebergs may subdivide has important implications regarding deterioration modelling and iceberg season severity forecasting. This paper describes the observed iceberg splitting and briefly discusses a statistically based deterioration model under development at C-CORE.

2. ICEBERG DETERIORATION MECHANISMS

The reduction of icebergs is a result of mass loss due both to melting and to calving. In seawater at 0° and below, melting will be insignificant. It will increase with increasing temperature and become extremely rapid at temperatures common off the Canadian east coast in the summer. Of course, this rapid melting will only take place where this warm water is in contact with the ice. Since the Labrador Sea usually becomes stratified in the summer, this warm layer may only be in the order of 10 to 20 m deep so that large bergs, say 2 million tonnes or greater, will only be melting rapidly along a 10 m wide girdle, a relatively small proportion of the entire surface area, while smaller bergs in the order of half a million tonnes or less will be more strongly influenced, as a much larger proportion of the surface will be exposed to the warm sea. In addition, due to the greater surface/volume ratio of smaller bergs, all things being equal, the proportional ice loss due to melting will be much greater in these bergs than in the larger ones. It would appear that melting will play a relatively minor direct role in the reduction of very large ice masses, although contributing significantly in the indirect role of inducing calving.

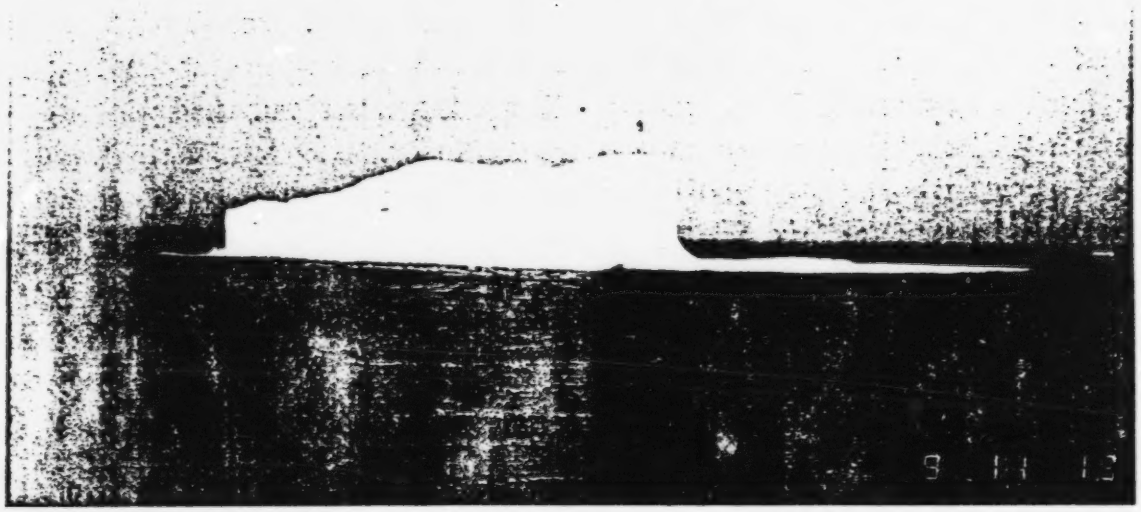
Calving, on the other hand, continues throughout the year to some extent. Since the ice lost in small calving events usually originates on the vertical faces, it seems clear that this will be the major means of ice loss for large bergs, while being minor for smaller masses. However, there is another scantily documented form of calving,

observed during DIGS '85 this past summer, resulting in enormous mass reduction. On two occasions a large tabular iceberg lost a large portion of its underwater mass through the calving of rams. Figure 1 shows this iceberg in the process of losing a ram. Both rams remained in the area for several days as small domed icebergs. On two other occasions, large icebergs split roughly in half by slumping in the middle and tipping such that the rams at either end heaved out of the water (see figure 2). It is thought that these two bergs were created by a splitting event themselves shortly before our arrival. If this is true, then this large mother berg produced six good-sized bergs in the course of about a week.

Both ram loss and large scale splitting are thought to be produced by the action of buoyancy forces. Buoyancy forces represent perhaps the most significant source of stresses in icebergs. All icebergs possess underwater rams of greater or lesser extent. Some can extend outward beneath the water surface for 50 m or more. Figure 3 shows an iceberg with a ram at the level of the water surface whose lateral extent was 70m or greater. Assuming that a large iceberg freshly calved from its parent glacier is of a tabular, blocky or near-tabular form, the development of these rams represents the first stage in its deterioration. After prolonged residence in the cold waters of Baffin Bay, little ablation will have taken place and no significant rolling. Any measurable amount of melting taking place will have done so at the water line, resulting in undercutting of the cliff faces and ice loss from them through small calving events. The underwater mass will be little affected and the berg will gradually take on an inverted T shape as indicated in figure 4, with often extensive rams extending outward from the sail. As the berg drifts south into the Labrador Sea and warmer surface waters, these rams will increase in extent as a percentage of the overall iceberg length..

The result of this is the establishment of regions of stress in the berg due to bending and shear forces. These stresses are caused by the upward buoyancy force acting on the rams. The maximum bending stress will occur along the centre line of the berg while maximum shear stress will occur along the vertical plane where the ram joins the central sail. The relative magnitudes will vary with underwater morphology and ice mechanical behaviour. Using elastic beam theory and simple iceberg geometry, estimates of shear and bending stresses due to buoyancy forces are possible. For example in the simply shaped iceberg shown in figure 4 with dimensions: length, l_w = 400m, thickness, H = 200m and breadth = 200m, maximum bending stresses will be about 0.34 MPa in a ram 25% of l_w (100m) while maximum shear stress will be about 0.24 MPa. In a ram 35% of l_w (140 m) maximum bending stress will be about 0.42 MPa with a maximum shear of about 0.33 MPa. A stress

Figure 1. Iceberg Freda. a) Immediately prior to ram separation. b) Recently separated ram partially hidden behind berg. c) Separated ram drifting off toward the right.



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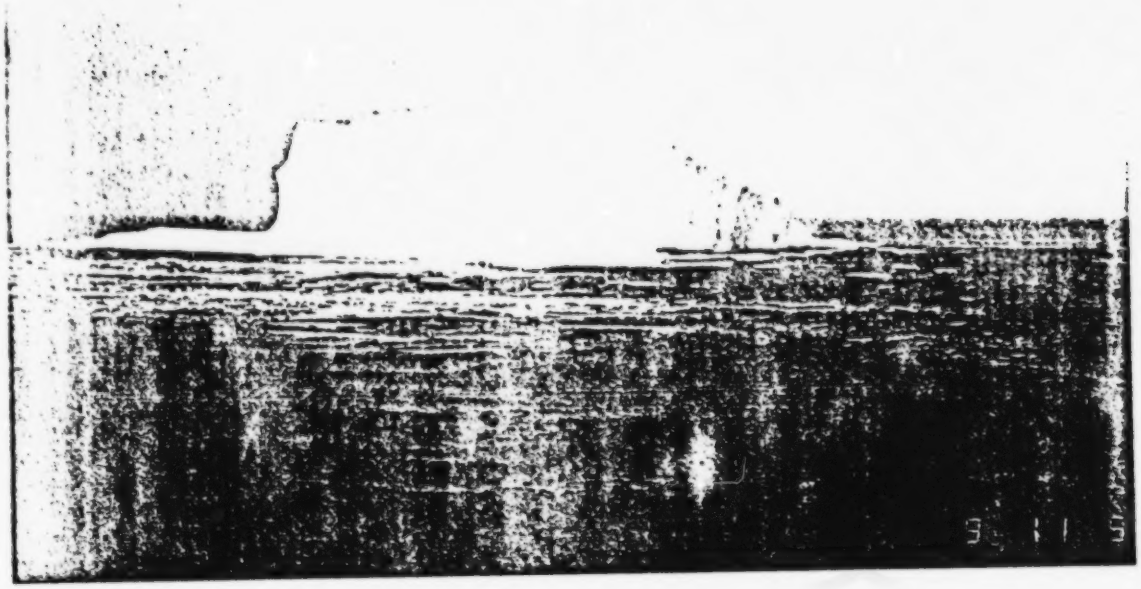

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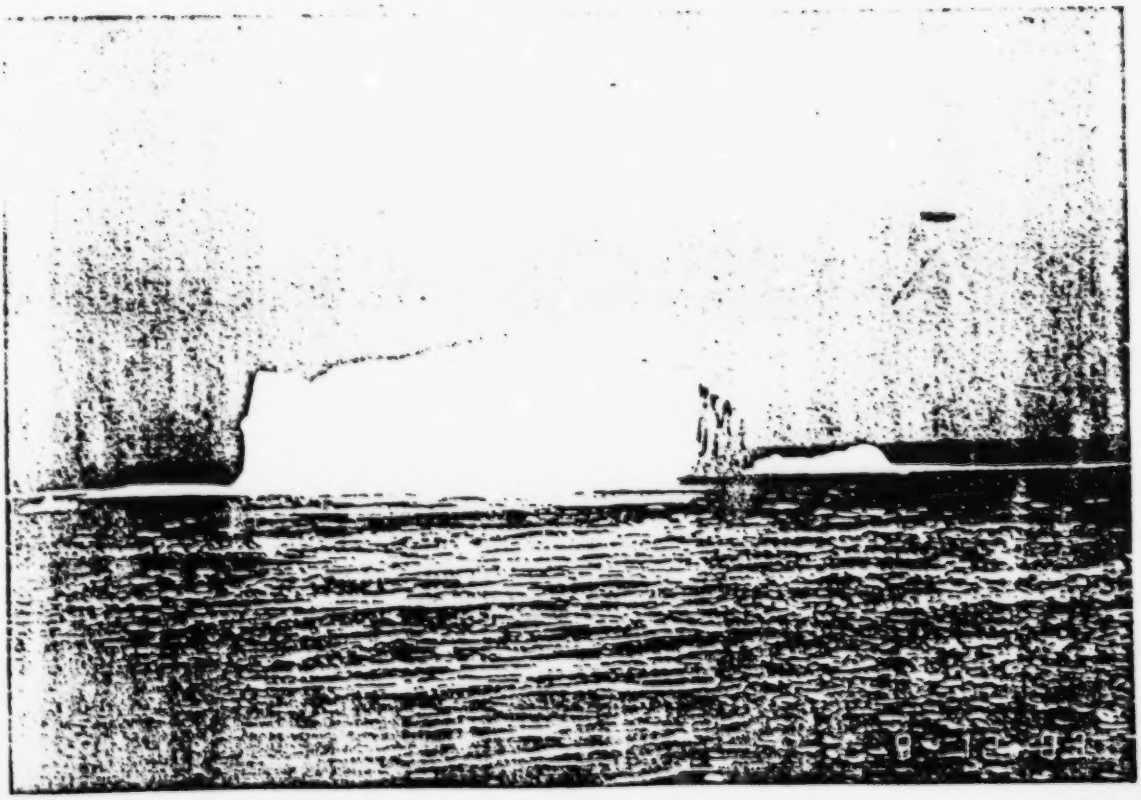

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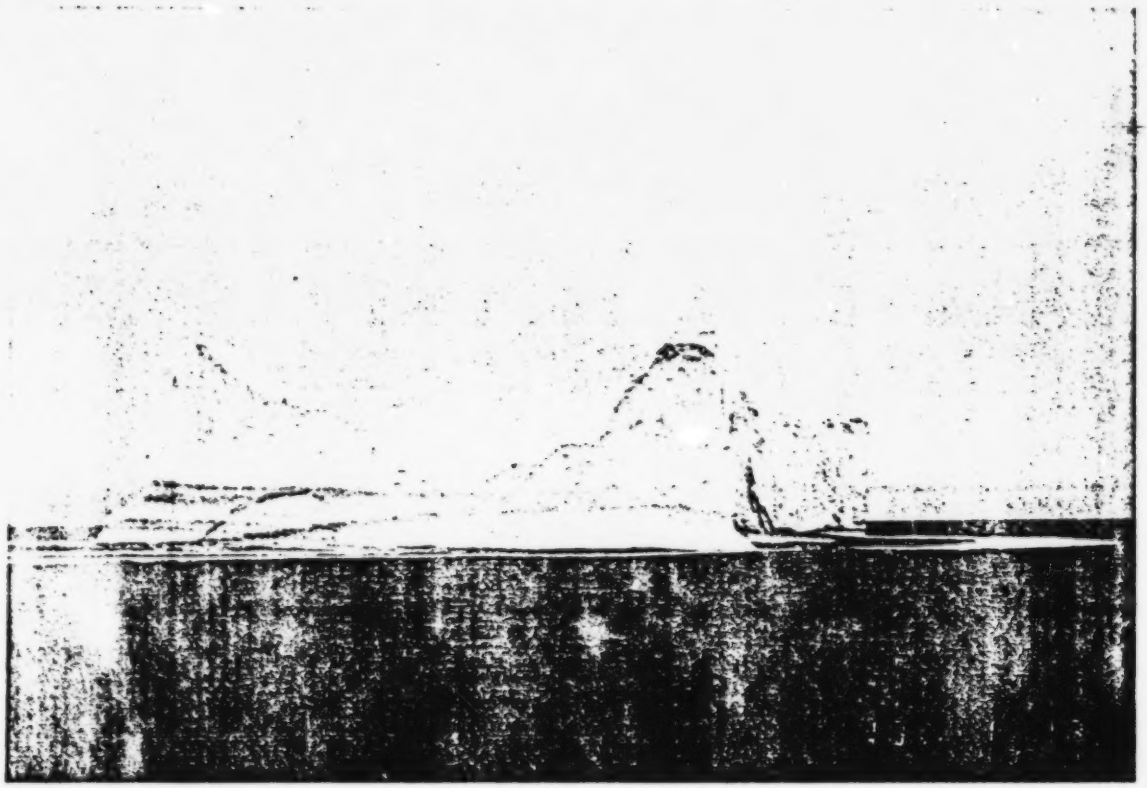
Figure 2. Iceberg Gladys. a) Immediately prior to splitting. b) Immediately after splitting. c) Separation of two daughter bergs.



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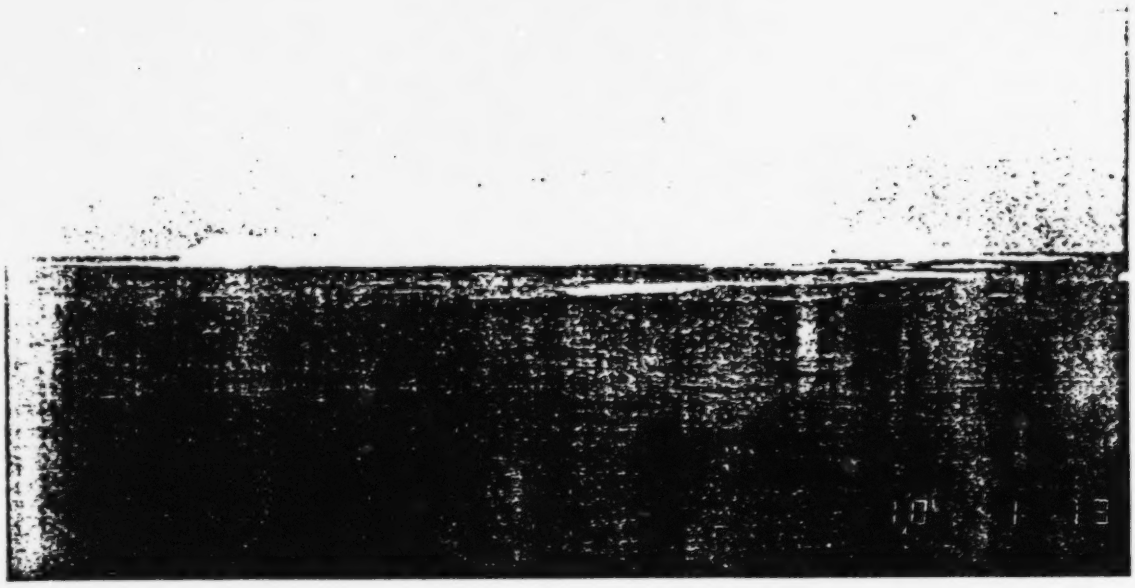

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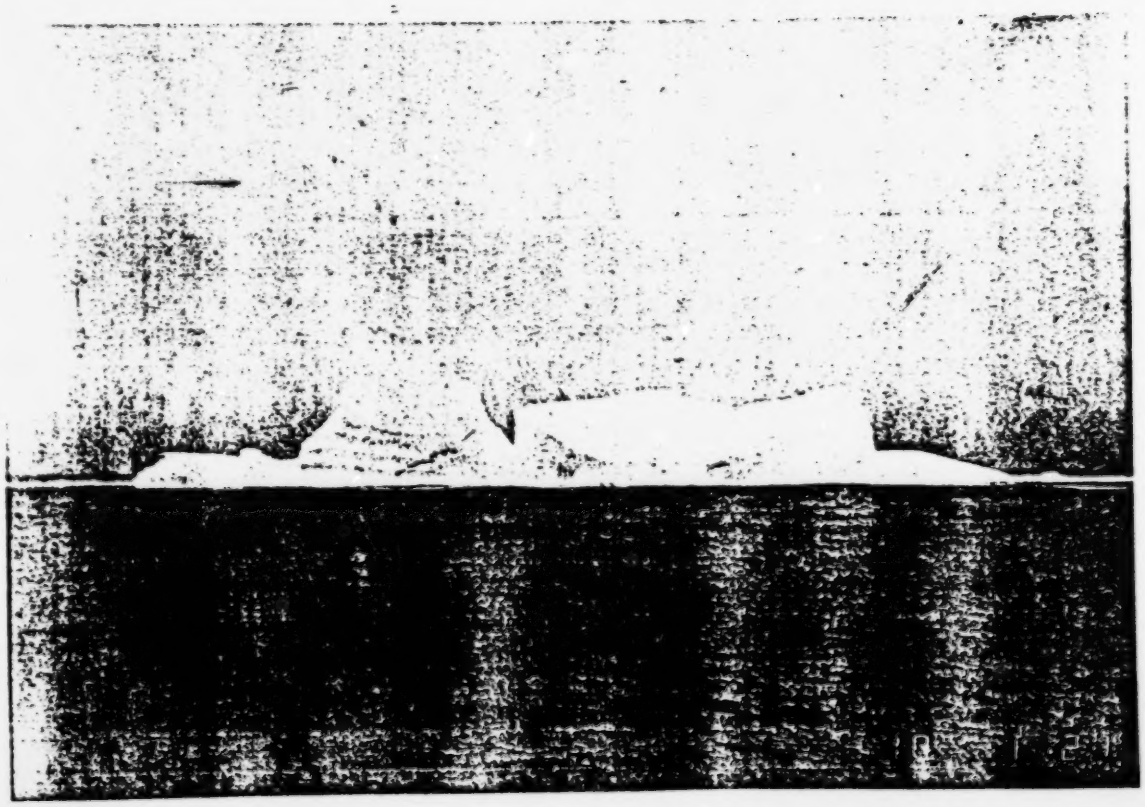

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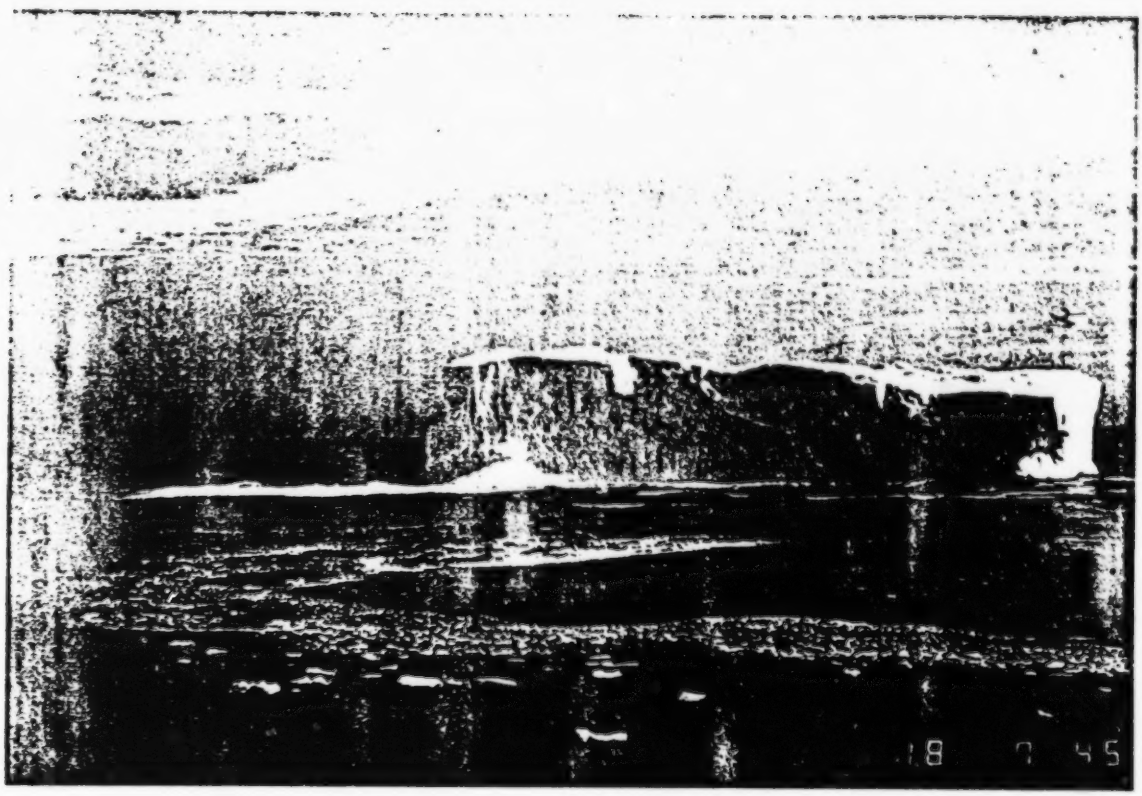

Figure 3. Iceberg Lucretia showing very long ram extending outward at the water surface at left.

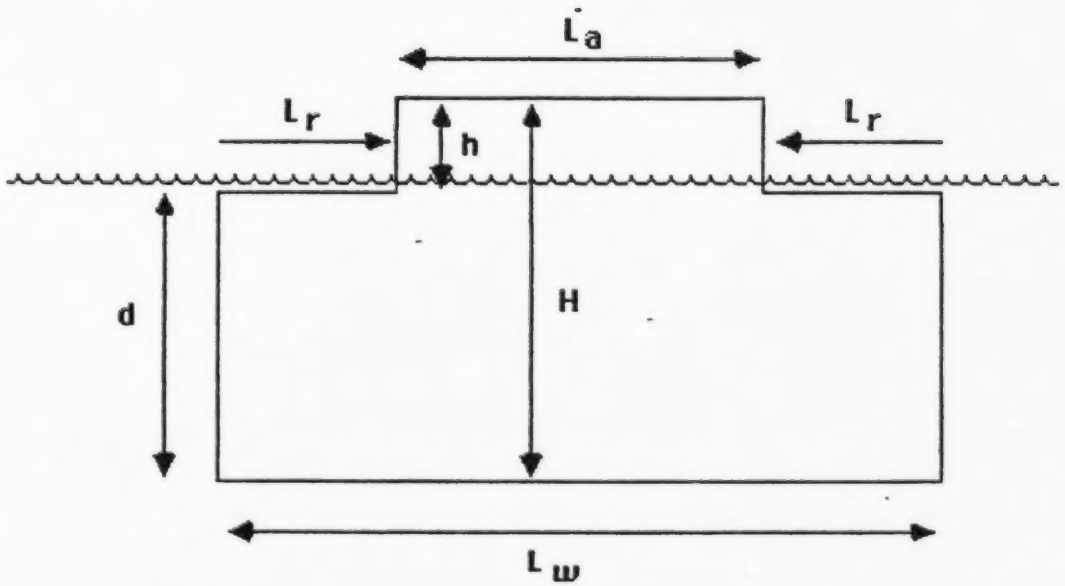

Figure 4. Schematic diagram of a partially ablated iceberg showing rams extending outward beneath the sea surface.

level of about 0.5 MPa may be sufficient to initiate tertiary creep. In addition, an ice mass of this size will almost certainly possess rehealed cracks, impurities or other areas of weakness which will facilitate crack formation/initiation. Evidence that little additional stress may be required for failure in many cases is provided by the above-mentioned major calving events in which two rams did break off and two large bergs failed virtually down the middle (Figures 1 and 2).

3. ICEBERG DETERIORATION MODELLING

These observations have important implications for the design of deterioration models, as the multiplication of icebergs is not accounted for in any of the existing models. In general, studies on the deterioration of icebergs have taken three forms: 1) laboratory model tests in which melting phenomena involved in the ablation process are studied. No estimates as to the significance of these phenomena in the overall reduction of the ice mass are given and the problem of calving is not addressed (*e.g.* Fuhs *et al.*, 1980; Josberger, 1982; Huppert, 1980). 2) large scale statistical studies on iceberg populations which focus on overall numbers or volumes of ice lost in the population in the process of iceberg drift from cold regions into warmer areas, but say nothing about the means of the loss (*e.g.* Morgan and Budd, 1978; Anderson, 1971). 3) theoretical studies of calving of icebergs and glaciers based on known mechanical and materials properties of ice in general (*e.g.* White *et al.*, 1980; Iken, 1977). These provide some useful input as they strive to discover, directly or indirectly, the mechanisms involved in the removal of masses of ice of various sizes, but cannot assess the relative importance of these mechanisms in iceberg reduction. Several operational models have been developed based on two or more of these model types (*e.g.* Anderson, 1983; Fenco, 1983), however, none have addressed the important issue of multiplication of icebergs due to large-scale splitting.

To investigate the influence of splitting on iceberg population and mass distributions, a statistical model must be used, since splitting is a ramdom event. A simple Monte Carlo simulation was developed at C-CORE whereby icebergs could be selected from an initial mass distribution and allowed to drift south from Davis Strait to the Grand Banks. Mass loss was assumed to be proportional to the product of a series of environmental factors reflecting average monthly fluctuations in sea surface temperature and the presence or absence of sea ice. Since wave erosion has been identified as the major melt mechanism (Anderson, 1983), mass loss was also assumed to be proportional to iceberg circumference. Using the available data on observed iceberg deterioration rates (Fenco, 1983), the constant of proportionality

was calculated.

As each berg was allowed to drift south, splitting was randomly permitted with a varying probability of occurance depending on mass loss factors; the higher the mass loss for a given berg, the greater its chances of splitting. The rate of splitting could be changed from run to run to investigate its influence on population and mass distributions at various latitudes.

While the model is still in the early stages of development, it appears that iceberg splitting repopulates the smaller size categories which have become depleted through normal ablation. If no splitting is permitted, large icebergs (greater than say 5 million tonnes) will arrive on the Grand Banks having undergone very little percentage mass loss while the more numerous smaller bergs will have been eliminated. This would lead to an underestimation of the total population and an overestimation of the median iceberg size. On the other hand if a very high rate of splitting is permitted, all bergs will be reduced to such an extent that both total population and median size will be underestimated. An intermediate rate of splitting may best be estimated by starting with scarce observations, then fine tuning to match measured population and mass distributions.

The interplay between splitting and ablation leads to a potentially useful implication for seasonal iceberg forecasting: the number of bergs expected on the Grand Banks is most significantly influenced by the number of large icebergs entering the Labrador Current via Davis Strait. Each of these large bergs will likely account for many smaller ones through a combination of splitting and ablation, while smaller bergs in the initial distribution will not as easily complete the journey south due to these same effects. Thus, a knowledge of the numbers of very large icebergs present off northern Labrador or Davis Strait may be sufficient to predict with some degree of accuracy the numbers to be expected on the Grand Banks say six to eight months later.

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